World Development Vol. 32, No. 12, pp. 2049–2064, 2004
Published by Elsevier Ltd.
Printed in Great Britain
0305-750X/$ - see front matter
www.elsevier.com/locate/worlddev
doi:10.1016/j.worlddev.2004.07.005

Estimating the Impact of Transgenic *Bt* Cotton on West and Central Africa: A General Equilibrium Approach

AZIZ ELBEHRI and STEVE MACDONALD *
Economic Research Service, USDA, Washington, DC, USA

Summary. — West and Central Africa (WCA)'s cotton sector is experiencing rising production costs and lower yields, reversing decades of growth. Declining input use, soil fertility and inefficient chemical pest controls are contributing factors. We evaluate the potential impact of *Bt* cotton on WCA using a multiregion general equilibrium model and multicountry estimates of *Bt*-induced productivity. We find that *Bt* cotton raises growers' returns, land value and welfare. Released labor from cotton is shifted to food crops hence reducing labor shortage constraints. Overall, results indicate that potential gross benefits from *Bt* cotton are substantial for WCA cotton sector, and that the economic costs of nonadoption are equally significant.
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Key words — cotton, biotechnology, crop productivity, West Africa, applied general equilibrium

1. INTRODUCTION

The growth of the cotton sector in West and Central Africa (WCA) [1] over the last four decades is one of the few bright spots in economic development of sub-Saharan Africa. Since the 1960s, cotton production in WCA has expanded substantially, making cotton one of the drivers of regional economic growth. Over 1961–2000, WCA cotton production grew by 20-fold while yields increased by more than four-fold (Figure 1). In many WCA countries, cotton is the main engine of rural employment, affecting the economic livelihood of over two million in Burkina Faso (16% of total population), and 2.5 million in Mali (18% of total) (Table 1). For five countries (Benin, Burkina Faso, Chad, Mali and Togo) the cotton sector represents between 5% and 19% of GDP, and cotton is the most important export commodity for several countries. Currently, the WCA's share of world cotton exports stands at around 15%, second only to the United States.

Several factors, both institutional and technological, have contributed to cotton growth in WCA. First, cotton production and marketing are vertically integrated, with state enterprises typically providing input credit and technical support, and purchasing all produced cotton from farmers. Access to credit and steady prices—often higher than alternative crops—has attracted farmers to cotton. Improved technologies, such as introduction of animal traction, fertilizers and insecticides have been critical in raising yields and expanding cotton areas. In the 1970s, other pest management innovations such as the ultra-light volume (ULV) spraying, the switch to more effective pyrethroid pesticides and to higher yielding upland (or US) cotton varieties also helped expand cotton area and production (Follin & Deat, 1999).

More recently, however, the WCA cotton sector has been showing declining yields, rising costs of production and eroding profitability (Ghura, Goreux, & Masson, 2002; Tefft, Staatz, Dione, & Kelly, 1998). These factors are compounded by WCA vulnerability to world price fluctuations in response to global demand and supply shifts. Moreover, the CFA franc devaluation in 1994 and the phasing out of input subsidies have induced short-term production costs leading to an extensification of cotton

* Final revision accepted: 7 July 2004.

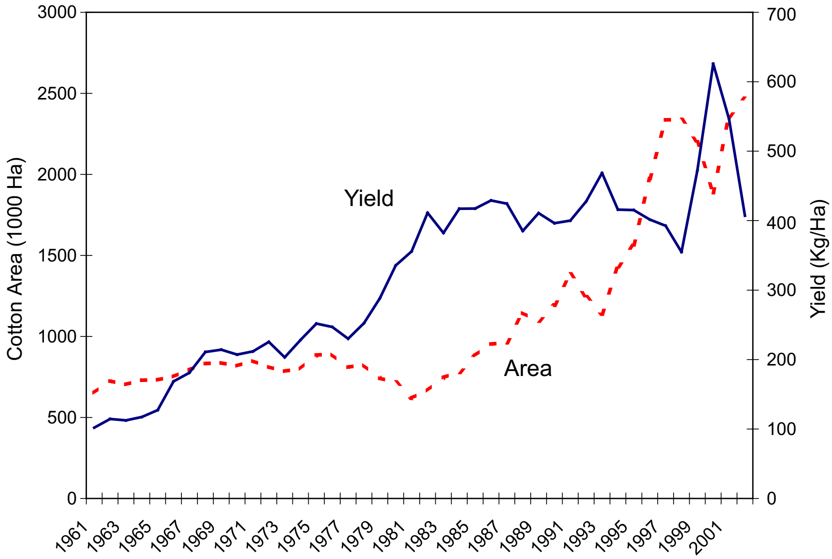

Figure 1. *Patterns of cotton area and yields for West and Central African region (Source: FAOSTAT, 2003).*

Table 1. *Importance of the cotton sector to West and Central African economies (1999)*

	Number of cotton farms (×1,000)	Cotton-dependent rural population (million)	Cotton share of total GDP (percent)	Cotton share of total export value (percent)	Ratio of cotton exports to food imports (% value)
Benin	NA	NA	8.8	44	88
Burkina Fas	250	2.0	6.9	58	99.5
Chad	400	NA	5.1	46	143.8
Mali	160	2.5	5	41	160.9
Togo	200	NA	4.9	19	169.6
Côte d'Ivoire	150	1.0	1.7	5	45.3
Cameroon	250	1.5	1.3	4	78.2
Central African republic	NA	NA	1.3	7	62.5

Sources: FAOSTAT (2003); *Coton et Developpement* (1999); NA: not available.

production with few input use. These changes have revealed the underlying weaknesses of the sector, and drawn attention to the need for longer-term productivity gains.

The emphasis on efficiency-boosting cost reduction requires a re-examination of chemical-based pest management at the core of the cotton production system in WCA, and the source of much of past yield gains (Follin & Deat, 1999). In recent years, however, yields have been falling even while pesticide use continues to increase (Ajayi *et al.*, 2002) revealing both short-term inefficiencies and long-term unsustainability. The increasing incidences of pest resistance to pyrethroids, particularly cotton bollworm (*Helicoverpa armigera*) are contributing to the declining effectiveness of pesticides (Martin, Chandre, Ochu, Vaissayre, & Fournier, 2002). Alternative approaches to calendar-based spray schedules, such as threshold applications or integrated pest management (IPM) methods are being tested in some WCA countries but the success is relatively slow (Ochut, Mattewest, & Mumford, 1998; Silvie, Deguine, Nibouche, Michel, & Vaissayre, 2001). Low levels of literacy, farmers' aversion to risk, and high requirements for insect scouting are all contributing factors.

Heavy reliance on insecticides is characteristic of most cotton production systems in the world. Indeed cotton uses 25% of world pesticides while covering only 2.5% of world cropland (Krattiger, 1997). But, rising pesticides resistance and increasing attention to environment and human health impact has motivated a re-examination of pesticide use. Up until 1996, there were very few real alternatives to pesticide use, and efforts to develop varietal resistance, biological-control and IPM had limited effect (Chaudhry, 1993). In this light, the release in the United States of transgenic *Bt* cotton in 1996 with resistance to bollworm-type insects represents a major technological breakthrough. Pest resistance to chemicals has become a serious problem in many cotton-growing regions. In the United States, cotton bollworm and tobacco budworm resistance to organophosphates has been rising since late 1980s and to pyrethroids since the early 1990s (Livingston, Carlson, & Fackler, 2003). In Pakistan and India, cotton bollworm developed into a major pest exhibiting increasing resistance to pesticides since early 1990s. The most dramatic case was China, where after decades of over-reliance on insecticides, a major outbreak of cotton bollworm in 1992 caused substantial crop and economic damage in several eastern provinces (Du, 2001). In subsequent years, a major share of China's cotton shifted to Western drier provinces with low pest pressures. In WCA, resistance of cotton bollworm to pyrethroids developed in many countries by 1996 (Martin *et al.*, 2002).

Adoption of transgenic *Bt* cotton was quite rapid in many countries. In 2003 over 37% of total cotton acreage in the United States was planted to *Bt* varieties; this compared to 25% in Australia, 30% in Mexico, 58% in China, 25% in South Africa, and 5% in Argentina (James, 2003). Direct farm-level benefits from the adoption of transgenic *Bt* cotton, through input cost reduction and increased yields, have been documented for the United States (Deville, Mullins, & Mills, 2002; Marra, Pardey, & Alston, 2002); China (Du, 2001; Huang, Hu, Rozelle, Qiao, & Pray, 2002; Pray, Ma, Huang, & Qiao, 2001); South Africa (Ismail, Bennett, & Morse, 2002); Mexico (Traxler, Godoy-Avila, Falck-Zepeda, & Espinosa-Arellano , 2001); Argentina (Qaim & de Janvry, 2002), and India (Qaim, 2003). Because of different ecological conditions and pest problems, not all cotton regions could equally benefit from the transgenic *Bt* varieties. But many other countries/regions such as WCA could benefit from the technology since cotton bollworm is the leading pest in the region and has become increasingly resistant to pyrethroid pesticides (International Cotton Advisory Committee—ICAC, 2000; Martin *et al.*, 2002). A key question is whether the WCA cotton industry can afford to fall behind technologically at a time when costs of production are rising and yields are trending downward.

In this paper, we examine the economic impact of transgenic *Bt* cotton adoption in WCA. We use a multiregion applied general equilibrium (AGE) model to quantify the effects on production, prices, returns to factors, and welfare resulting from *Bt* -induced productivity boost. The application of the multiregion AGE framework in technology evaluation is justified on several grounds. First, given the economic significance of cotton to WCA, the impact of *Bt* cotton will extend to rural employment, GDP and exports, all of which are more suitably examined within an economy-wide framework. Second, given that transgenic *Bt* cotton adoption is pervasive in many regions, the impact on WCA depends not only on adoption within the region but also the extent of adoption in other regions. Moreover, the high dependency of WCA on world cotton trade makes the multiregional framework more suitable to explore the trade implications of technical change.

In this analysis we pay particular attention to the estimation of crop productivity gains due to transgenic *Bt* cotton for all adopting regions. Total factor productivity (TFP) is estimated from farm-level economic impact analyses of *Bt* cotton and a comprehensive multicountry 2001 cost of production survey for cotton by ICAC (2001a). In simulating the impact of transgenic technology, we consider both factor-neutral and factor-biased technical change assumptions.

The remainder of the paper is as follows. Section 2 reviews the recent global trends in cotton yields, pesticide use, and the transgenic technology. Section 3 reviews the evolution of WCA cotton productivity trends and underlying determinants of the sector's inefficiencies. Section 4 describes the modeling framework and database, while section 5 presents the simulation scenarios. Section 6 presents the results while Section 7 provides a summary and conclusion.

2. GLOBAL COTTON: YIELD TRENDS AND TECHNOLOGY

Over 60 countries worldwide, both developing and developed, produce cotton (Figure 2).

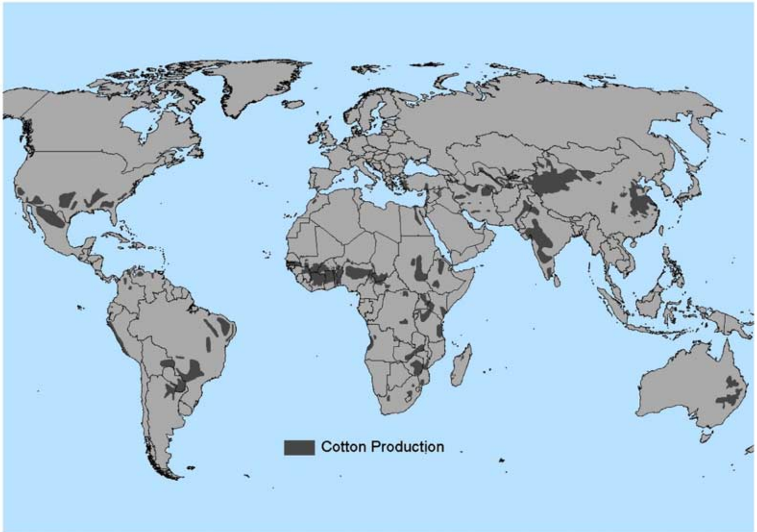

Figure 2. *World cotton regions (Source: Compiled from country cotton maps from USDA, 1994, and for Africa from Coton et Developpement, 1999).*

Since the 1950s there has been a tripling of production over a fairly stable land area (around 30–32 million hectares) driven by substantial and quite generalized yield increases. Technological innovations and practices such as irrigation, fertilizer use, insecticides, new varieties, mechanized harvesting, and use of herbicides all have contributed to yield gains with varying degrees and timing depending on countries (Follin & Deat, 1999).

Since the late 1980s yield gains in cotton have either slowed or stopped for most countries (Figure 3) while in some regions such as Central Asia, there has been yield contraction. Several

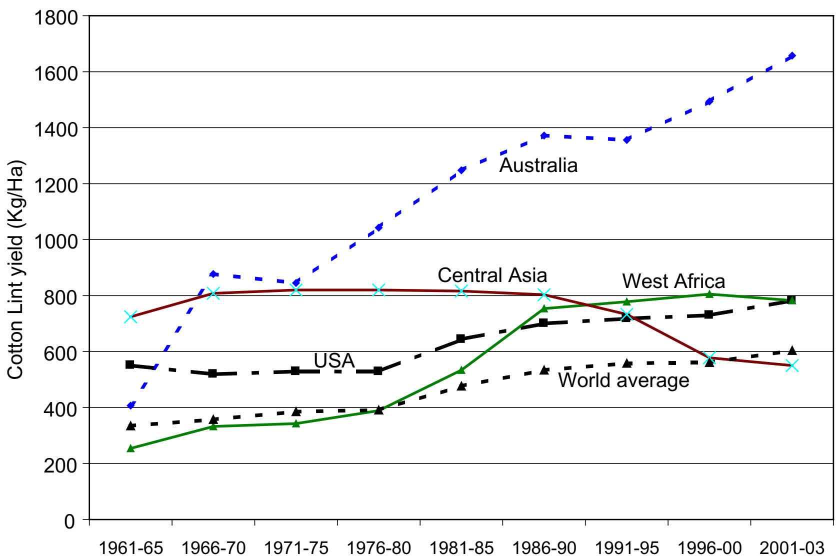

Figure 3. *World cotton yield trends (Source: FAOSTAT, 2003).*

reasons are advanced for these trends. For some countries (the United States), the technological improvements responsible for earlier yield increases have been exhausted. Plant breeders and geneticists point to the difficulty of achieving additional gain in potential yield, given the complexity of the agro-ecology of the cotton plant and a continuing knowledge gap of the genetic control for such yield parameters as boll number or size (Azfal, 1990). There is also a shift of breeding objectives from yield enhancing to cost reducing traits (i.e., insect resistance), which bring economic value to the producer without necessarily increasing potential yield (Follin & Deat, 1999).

A far more critical factor in cotton production and yield trends is the role of chemical use in pest control, which (more than for other crops), has been at the core of cotton production systems in much of the world since insecticides became widely available following WWII. The heavy reliance on insecticide use made cotton the highest consuming crop in the world. In many developing countries cotton's share of national pesticide use is extremely high (Figure 4). In Pakistan and India, for example, cotton consumes 70% and 53% of total pesticide, respectively, while cotton cropland share is only 5.4% and 14%. In Africa, the cotton share of total pesticides is among the highest in the world, reaching in many cases 80% or more.

Pesticide use in cotton has been critical to yield increases or preventing yield loss from pest attacks. Field trial research has shown repeatedly that without insecticides a significant share of yields, ranging from 25% to 50% or more, can be lost (Oerke, Dehne, Schonbeck, & Weber, 1995; Yudelman, Ratta, & Nygaard, 1998). Extensive use of chemicals over the years, however, has given rise to increased incidences of pest resistance, elimination of natural enemies and outbursts of secondary pests. In many cotton-growing regions, cotton bollworm has emerged as the most serious pest in cotton, with increasing resistance to insecticides (organophosphates, pyrethroids).

Besides growing pest resistance problems, there is also widespread recognition that chemical pesticides are harmful to human health and the environment (Yudelman *et al.*, 1998). Adverse effects of pesticide are considered to be greater in developing countries, since most farmers either are not properly equipped or they do no follow instructions in the safe use of pesticides (Pingali & Roger, 1995). Field surveys among cotton producers across many countries from India, Central America, Malaysia, Uganda, Brazil and the former Soviet Union indicate that around half of the cotton farmers claim sickness due to pesticide use (Repetto & Baliga, 1996). In China, during 1992 major pest outbreak and following extensive chemical treatments, 100,000 poisonings were reported due to pesticide spray and 1,000 deaths, with a large percentage related to cotton (Du, 2001). In Zimbabwe, Mumbe

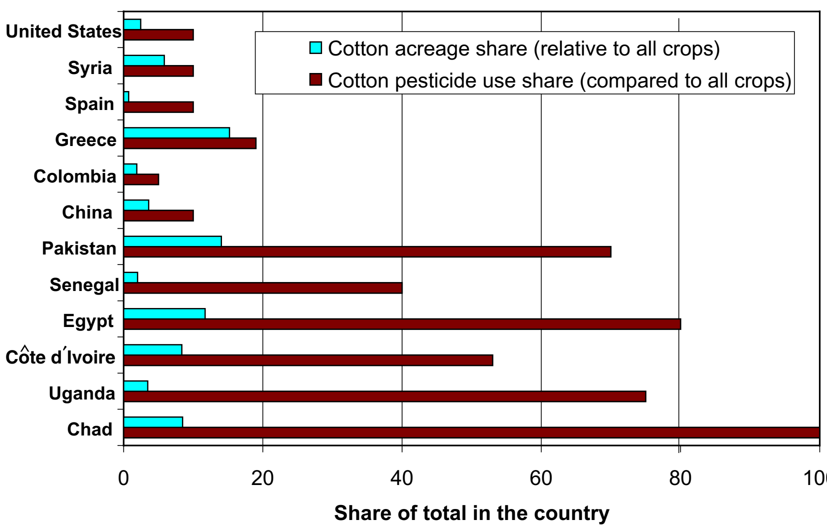

Figure 4. *Selected countries cotton share of crop and pesticide use (Sources: ICAC, FAO).*

and Swinton (2002) estimated farmers' health-related costs of pesticides for 1999 equivalent to 45–83% of pesticides expenditures. In Mali, Ajayi *et al.* (2002) estimated the human health cost to pesticide use equal to 40% of the total pesticide market value.

The release in the United States since 1996 of transgenic cotton variety resistant to *Lepidopteran* insects (*Bt* cotton) offered a significant ability to control a group of bollworm insects (tobacco budworm, cotton and pink bollworm). Its insect resistance derives from the presence of bollworm-resistant gene (Cry1A) isolated from a soil bacterium, *Bacillus turingiensis* (*Bt*). The *Bt* cotton was quickly embraced in several countries and by 2003, over 7.2 million hectares or 20% of total world cotton acreage is under transgenic *Bt* cotton (James, 2003).

Direct economic benefits to farmers growing transgenic *Bt* cotton have been documented for adopting countries. Table 2 summarizes estimates of economic benefits from *Bt* cotton from farm level studies that compared input costs, yield and net return differences between *Bt* and non-*Bt* cotton fields. For example, in China data over 1999–2001 show that pesticide costs were reduced by over 80% due to *Bt* cotton, labor costs were reduced by 15%, and while seed cost increases from 50% to 670%, the value of output rose from 6% to 20% depending on the year. These studies show that where *Bt* cotton is grown, there are significant economic gains to producers. Moreover, these studies offer only partial estimates. They leave out indirect savings in water often required in large quantities for manual-based pesticide sprayings. In addition, spillover effects from improved farmers' health are also unaccounted for. On the other hand, these gains reflect short-term effects whose magnitude may change from year to year and from one region to another depending on pest pressures. Moreover sustained economic benefits also depend on effective resistance management strategies to prevent insects developing resistance to *Bt* toxin produced by the transgenic plant. Such resistance strategies will depend on enhanced understanding of pest genetics and resistance mechanisms, cross-resistance to *Bt* toxin and the impact of refuge implementation in the field (Brousseau, Masson, & Hegedus, 1999).

Table 2. *Estimates of Bt cotton impact on input cost and yield/net returns changes in cotton*

Country/source	Input cost changes from *Bt* cotton			Net return/output advantage due to *Bt* (percent)
	Savings in insecticides (percentage)	Seed cost increase[a] (percentage)	Labor saving (percentage)	
United States				
Deville *et al.* (2002)				9.0
Marra *et al.* (2002)[b]	−17.0			14.3
China				
Hebei region, 1999 (Du, 2001)	−82.0	673.0		14.6[c]
Shandong region, 1999 (Du, 2001)	−84.0	50.0		20.0[c]
Huang *et al.* (2002)	−83.3	120.0	−9.5	5.8[c]
South Africa				
Ismail *et al.* (2002)	−34.0	109.0		18.0
Mexico				
Traxler *et al.* (2001)	−77.0	500.0		8.5[c]
Argentina				
Qaim and de Janvry (2002)	−46.0	166.0	17.0	33.0[c]
India				
Qaim (2003)	−59.0	386.0	34.0[d]	58.0[c]

[a] Inclusive or technology tees.
[b] Unweighted average of state-level impacts assessments from 1997 through 2001 compiled by the citation authors.
[c] Output advantage of *Bt* cotton in percentage value.
[d] Inclusive of reduced labor costs from insecticide use and increased harvesting labor cost due to larger yields.

3. COTTON IN WEST AFRICA: PAST SUCCESS, PRESENT WEAKNESS

Most cotton regions in WCA are located within two agro-ecological zones: the semi-Arid region (south of the Sahel) and the subhumid region (north of the humid tropics). It is roughly within the semi-arid zone that WCA cotton production first spread in 1960s with the introduction of animal traction, the opening up of new cotton areas (by cutting savanna shrubs), and government promotion of fertilizer and insecticide use (Follin & Deat, 1999). Expanded insecticide use and the introduction of the ultra light volume (ULV) spray method, which relieved farmers from the need to transport large quantities of water to the field, the introduction of pyrethroid pesticide in 1977, and the higher yielding upland cotton type (*Gossypium hirsutum*), [2] also stimulated further expansion of cotton cropland in the subhumid area and the tropics (South of Benin, Côte d'Ivoire Coast and Togo). Overall, the generalized use of pesticides has played a key role in cotton area expansion and yield gains in virtually all of WCA region between the late 1960s to early 1980s. Nowhere in WCA was there any viable production of cotton without the spread of pesticides and to lesser extent fertilizer. The estimated yields in WCA without pesticides would be 30–50% lower (Follin & Deat, 1999).

Toward the end of the 1980s, however cotton yields in much of WCA began a downward trend (Figure 1). There are several factors underlying these yield reversals. First, a trend toward extensification and lower input use in cotton production arising from loss of profitability (fluctuating cotton prices) and higher input cost (subsidy removal, 1994 CFA franc devaluation). Second, cotton cropland expansion created a labor shortage. Cotton is relatively labor intensive in WCA, so expanded acreage led to more reliance on family labor and insufficient field maintenance (Tefft *et al.*, 1998). Expansion of cotton area also led to a decrease in fertility due to shortening of follow periods, which contributed to lower yields. Another factor was reduced effectiveness of chemical pest control due to rising pest resistance and inappropriate practices. Under the vertically integrated cotton production, farmers often follow rigid and increasingly ineffective calendar-based spraying as required by input-supplying cotton companies. These methods are followed because they can be easily implemented by less educated farmers with limited extension services. Rising pesticide resistance problems, particularly by cotton bollworm, have become so serious that in 1998 Burkina Faso, Côte d'Ivoire, Mali, Benin, Guinea and Senegal started a regional insecticide resistance project (ICAC, 2001b) and began experimenting with alternative methods such as threshold-based spraying or IPM methods which take into account insect populations or damage thresholds.

Given fluctuating world prices that are outside the region's control, decreasing cotton yields and rising costs of production have put the future viability of the WCA cotton in question. Both institutional and technical innovations are required to improve the viability of the sector, including institutional reforms to ensure public/private efficient input delivery systems, alleviate input credit market failure and improve coordination within the supply chain (Boughton, Tschirley, Zulu, Ofico, & Marrule, 2003). These will not be sufficient, however without technological innovations that improve varietal use, pest management and cotton quality. A critical component of these productivity-boosting technologies is improving the efficacy of pest management. Current attempts at testing threshold spraying schedules may work only in the long run given the current slow adoption rate stemming from the low literacy level of farmers and the requirements for insect scouting (Ochut *et al.*, 1998). Alternatively, recent technologies such as transgenic *Bt* cotton may offer promising alternatives for boosting productivity, given their apparent success in other regions.

4. TRANSGENIC COTTON IN WEST AND CENTRAL AFRICA: AN AGE ANALYSIS

In this paper we employ the Global Trade Analysis Project (GTAP) [3] model (Hertel, 1997) to examine general equilibrium impacts of transgenic *Bt* -adoption in WCA. The approach applied here differs from single-commodity or multimarket partial equilibrium approaches (Alston, Norton, & Pardey, 1995). Those models evaluate technological innovations by examining the impact of a supply curve shift for a single commodity, holding production and prices of other commodities fixed. The advantages of these models include modest data requirements and more institutional detail. They also make several limiting assumptions, such as fixing prices and production of other commodities, and are weak in evaluating the impact of pervasive technological change across multiple regions. Moreover, these models do not explicitly account for factor markets. This is critical in examining the impact of new technologies on returns to owners of land, shifts in labor and land use. By contrast, the AGE approach offers a more general framework for analysis of technological change by allowing for endogenous movements of regional prices and quantities in response to technological change, while explicitly accounting for price movements both horizontally and in vertically related markets.

The GTAP is a relatively standard, multiregion model built on a complete set of economic accounts and detailed inter-agency linkages for each of the economies represented. The underlying data structure for the model is the GTAP data base, version 5.2 (Dimaranan & McDougall, 2002). The GTAP production system distinguishes sectors by their intensities in five primary production factors: land (agricultural sectors only), natural resources (extractive sectors only), capital, and skilled and unskilled labor. Factor markets are treated under fixed supplies with flexible wages and land rents. This closure reasonably captures the tight labor constraints in cotton production in WCA. In trade, products are differentiated by country of origin, allowing bilateral trade to be modeled, and bilateral international transport margins are incorporated and supplied by a global transport sector.

The model determines relative prices in Walrasian sense. All the goods, service and factor markets simultaneously clear under a perfect competition assumption. In addition savings-investment and expenditure-income are also in balance. The price links in the model differ from partial equilibrium models. Domestic prices of exported and imported products are determined by world market prices plus any trade taxes-cum-subsidies. Moreover, goods prices are CES cost functions of import prices and domestically produced goods prices. The degree of price transmission depends on both trade elasticities and on trade shares. In addition, there are links working through intermediate inputs, which include imported and domestic goods, and finally through primary factor prices. Like most CGE models, consumers pay producer prices (corrected for taxes or subsidies), but marketing services are not accounted for at the sector level (like cotton). Rather marketing and distribution services are represented by a single aggregate sector. While simplistic, this assumption doesn't affect directly the outcomes of the present analysis since we do not model the impact of changing marketing efficiency in WCA cotton rather we focus on the implications of productivity impacts of cotton production.

Cotton policies like other commodities are captured in the model in the form of *ad-valorem* equivalents of border measures and domestic support. Import tariffs on cotton and any export taxes-cum-subsidies (European Union, China) are represented in the model as taxes wedges. For domestic support policies, direct support payments in the case of OECD countries (United States, European Union) is derived from OECD published producer subsidy equivalent (PSE) and modeled either as cotton output subsidies, land-input subsidy or capital-input subsidy, depending on a country. The same approach was also followed for non-OECD countries (China, India). Cotton policies, however are not changed in the analysis since our focus is to isolate the impact of technology-induced impact of *Bt* cotton across a range of countries with diverse cotton policies.

The model aggregation is based on the version 5.2 of the GTAP database. The original 66 regions are aggregated into 15 regions, separating out the major cotton producers in the world as well as the *Bt* cotton adopting countries (see Table 5). The commodity aggregation consists of 12 sectors: Cotton, Other Crops, Fruit & Vegetables, Other Agriculture, Primary sectors, food processing, Textiles, Clothing, Chemicals, heavy industry, Other Manufacturing, and Services.

We model the impact of transgenic *Bt* cotton adoption in terms of crop productivity change defined as the value of cotton output divided by the value of all inputs. In this paper, we pay particular attention to the estimation of *Bt*-induced cotton productivity for each of the *Bt* -adopting region in the model. In estimating the productivity shocks we calculate percentage change in cotton output and input use (insecticides, seed, labor) due to *Bt* technology. For labor we consider the net change resulting from estimates of labor savings from lower pesticide applications *and* increased labor required to harvest the additional cotton output per acre due *Bt* technology. The final overall *Bt* cotton-induced productivity change is then calculated, taking into account per-unit value of

Table 3. *Calculated Bt-cotton induced total factor productivity for Bt cotton adopting regions*

Model regions	Regional share of world cotton production (percentage)	Input cost and yield changes with *Bt* cotton compared to non-*Bt* cotton (percentage)[a]				*Bt* cotton adoption rate (percentage)[b]	*Bt* cotton-induced productivity change[c]
		Insecticide	Seed[d]	Labor	Yield		
Australia	4.3	−80	80	−2	0	25	3.24
China	15.1	−82	220	−9.5	15	58	7.65
India	16.0	−49	386	34	58	25*	10.20
USA	15.5	−80	80	−2	0	37	1.74
Rest of North America	2.7	−77	166	−15	8.5	30	1.49
Latin America[e]	7.5	−46	166	17	33	5	1.85
South Africa	1.3	−25	110	−8	18	40	8.21
West and Center Africa	5.1	−25	110	−8	18	25*	5.29

[a] Authors calculated shares based on farm level studies for Mexico (Traxler *et al.*, 2001); China (Du, 2001; Huang *et al.*, 2002); South Africa (Ismail *et al.*, 2002); Argentina (Qaim and de Janvry, 2002), and India (Qaim, 2003). For Australia, *Bt* cotton impact use is on yield and input assumed to be similar to those of the United States; for India, yield and input impact are assumed to be similar to those of China.

[b] 2003 levels of adoption for all regions that have adopted *Bt* cotton. * Assumed rates for West africa and India with the expectation that this rate will be reached within few years from technology introduction.

[c] For an explanation of how these productivity rates are calculated, see Section 4.

[d] Inclusive of technology fees.

[e] Latin America includes cotton producing regions of the Americas except NAFTA countries.

input and output for cotton, and scaled by *Bt* cotton adoption rate for each region (Table 3, last column). Several data sources are used. Farm-level studies for each adopting region where used for costs and returns differentials between *Bt* cotton and non-*Bt* cotton (Table 2). The ICAC cost of production survey for 2001 was used to derive input cost shares for pesticide and seed. [4] Labor cost share for cotton are taken from GTAP database. For all *Bt* cotton adopting regions, we use the *Bt* cotton adoption rates for 2001 and assume they are unchanged during the model simulation. For WCA we assume a 25% adoption rate of *Bt* cotton and use the same rates for input and output change as calculated for South Africa. We chose South Africa as a proxy for WCA given similarities in terms of pest pressure, inefficient chemical control, and small scale farming conditions (Ismail *et al.*, 2002). For nonadopting regions in the model there is no change to cotton productivity.

5. MODEL SCENARIOS

To estimate the economic impact of transgenic *Bt* cotton on WCA, we compare an adoption scenario (by eight regions including WCA) to the status quo in which transgenic cotton is only used in other seven regions but not WCA. Under the status quo scenario (E1) the cotton sector in WCA continues along the recent path of declining productivity. The negative technology shock used in this scenario is derived using recent data on average yields (declining 2.5% annually) for WCA cotton and pesticide costs (rising 1.1% annually, based on time-series data for Mali) (Ajayi *et al.*, 2002). The cotton yield decline can be attributed to several factors. First, there is the reduction in input (fertilizer) use from higher prices and lower subsidies. There is also the long run impact of declining soil fertility arising from reductions in fallow land and negative net soil nutrient balances. [5] Third, are the increased pest problems and increasingly ineffective chemical controls.

In calculating the negative productivity impact from declining yields in the status quo scenario (E1), we only take into account the last factor—that is, the problem with pesticide management. Given the lack of data needed to decompose the contribution of each of the three factors above to yield erosion, we make the assumption that the contribution of ineffective pesticide management to yield erosion is proportional to the cost share of pesticide use to total cost. The larger the pesticide cost share, the greater the impact of pest problems and pesticide management on yields. The resulting calculated (negative) productivity rate for WCA of −2.3% used in the status quo scenario which represents negative productivity trends under current pest management practices. This offers a more realistic basis to compare with the alternative scenario where WCA adopts transgenic *Bt* cotton.

Under scenario E2, WCA plus seven adopting regions receive a positive productivity shock (reported in Table 3, last column). In the WCA case, the productivity shock of 5.29% is equivalent to a downward shift of the unit cost function by 5.29%, all else being equal. This is the rate at which cotton crop productivity grows relative to other sectors due to transgenic *Bt* technology over the simulation horizon.

In both scenarios E1 and E2, crop productivity is treated as factor-neutral (or Hicks-neutral) technical change that uniformly reduces the input requirements associated with producing a given level of cotton output. However, we know that factor neutrality assumption in technical change is not an innocuous one and that prices, sectoral employment, and returns to primary factor owners are sensitive to assumptions about the bias of technical change (Frisvold, 1997). Moreover, the transgenic *Bt* technology affects most directly chemical inputs and labor usage. Therefore, we compare the adoption scenario E2 to two additional scenarios under factor-biased technical change. In scenario E3, we treat *Bt* induced productivity as labor-augmenting technical change and adjust the size of the shock used in E2 by the labor cost share to achieve equal rates of cost diminution between E2 and E3. In scenario E4, we treat *Bt*-induced productivity as a combination of labor and chemical input-augmenting technical change using the same cost share scaling as in E3.

6. RESULTS

Table 4 reports the percentage change in selected variables for WCA under all four scenarios. Under scenario E1 (no transgenic *Bt* technology for WCA; adoption in seven other regions), the sectoral and aggregate situation worsens for WCA as it continues along a negative productivity trend. Cotton output in WCA decreases by 7.6% (−$US 180.5 million constant 1997) while cotton price (relative to consumer price index) rises by 1.97%, resulting in greater revenue losses for WCA cotton growers. In this scenario, WCA forgo not only the productivity boost from *Bt* cotton but experience a loss of productivity which raises the per unit cost of cotton, and pushes its price up given the zero profit condition. In this case West Africa cotton is now relatively more expensive compared to other regions which adopt *Bt* cotton, boost productivity and pushes aggregate world cotton price down (−3.76%) (Table 4).

Price for land under cotton falls more than for other crops. Land use in cotton declines by 4.41%, as some land is diverted to Other Crops (+0.23%) and Fruit & Vegetables (+0.25%). Labor also moves out of cotton (−5.57%) and into Other Crops (+0.13%). The aggregate impact for WCA is a decrease in returns to land while wages are down relative to the price of purchased commodities. Cotton exports decline by −14.46% (−$US 174.5 million) while the region's global export share decreases from 12.21% to 10.44%.

Under scenario E2, where WCA adopts transgenic *Bt* technology along with other seven regions, cotton output increases more (5.14%) than the cotton price decline (−5.05%). As the domestic market price for cotton in WCA declines by a lower rate than the productivity shock (+5.29%), we have rising returns to agricultural production which are capitalized into land values. Cotton land price barely change (−0.09%) and wages slightly rise (+0.07%) relative to prices of other purchased commodities. Land use and employment are shifted away from Other Crops and into cotton. Cotton output expansion also generates downstream impacts on textiles and clothing in WCA; output in these industries increases by 0.54% and 0.67%, respectively. As the majority of produced cotton is also exported, the increase in cotton output also leads to export expansion (+9.58% or $US 115.2 million) and world cotton export shares of WCA rise from 12.2% initially to 13.38% under E2. In terms of social welfare, as measured by the Hicksian equivalent variation, the no-adoption scenario for WCA (E1) results in a welfare loss of $US 87.61 million (Table 4, lower panel). By contrast, under the *Bt* adoption scenario (E2) domestic welfare for WCA increases by $US 81.91 million due to gains in technical efficiency ($US 115.23 million) and allocative efficiency ($US 8.47 million) which more than compensates for terms of trade losses (−$US 41.79 million). The negative terms of trade effects are

Table 4. *Output and price impact of cotton productivity for West and Central Africa (WCA)*[a]

(Percentage change)		*Bt* cotton adoption by WCA		
Variables	Status quo for WCA (no *Bt* cotton adoption) E1	Factor-neutral *technical change* E2	Labor-augmenting *technical change* E3	Labor-augmenting and chemical-reducing *technical change* E4
Output				
Cotton	−7.61	5.14	4.23	3.57
Other crops	0.14	−0.05	−0.03	−0.03
Textiles	−0.30	0.54	0.51	0.46
Clothing	−0.07	0.67	0.65	0.59
Output prices				
Cotton	1.97	−5.05	−4.57	−4.26
Other crops	−0.08	0.04	0.04	0.04
Textiles	0.26	−0.75	−0.69	−0.64
Clothing	0.07	−0.26	−0.25	−0.23
Employment				
Cotton	−5.57	−0.15	−6.83	−5.11
Other crops	0.13	−0.06	−0.02	−0.02
Textiles	−0.26	0.55	0.58	0.52
Clothing	−0.02	0.68	0.73	0.66
Land use				
Cotton	−4.41	−0.09	1.70	1.54
Other crops	0.23	−0.01	−0.10	−0.09
Fruits and vegetables	0.25	0.33	0.01	0.02
Other agriculture	0.36	0.39	0.08	0.09
Cotton exports				
Percent change	−14.46	9.58	7.74	6.51
World export share (%)	10.44	13.38	13.16	13.00
Factor returns				
Land	−0.75	−0.09	0.43	0.37
Labor	−0.09	0.07	−0.01	0.00
Cotton world price (%)	−3.76	−4.20	−4.17	−4.15
Aggregate national income (%)	−0.18	0.08	0.06	0.06
Welfare ($US million, 1997)				
Equivalent variation	−87.61	81.91	78.09	69.43
Allocative efficiency	−18.21	8.47	10.93	7.03
Technical efficiency	−50.51	115.23	106.95	99.19
Terms of trade	−18.89	−41.79	−39.79	−36.80

Source: Authors' simulation results.
[a] In all scenarios, other *Bt* cotton-adopting regions also benefit from *Bt*-induced productivity increase.

expected given the price reducing effect of the technical change on cotton.

To what extent do our results differ when we change our assumption of technical change from factor-neutral (column 2, under E2) to factor-bias? (Last two columns of Table 4 under E3 and E4). Under scenario E3, the *Bt* technology impact works through labor-augmenting technical change and both cotton output and price effect is smaller than under scenario E2. A bigger difference is the return to land, which is much larger under E3 (+0.43%) compared to E2 (−0.09%). Under scenario E3, as labor becomes more productive, lower net labor is required per unit of output, and as cotton production expand, demand for additional land is larger (1.70% increase) compared to scenario E2 (−0.09%). Hence, more

Table 5. *Global impact of transgenic Bt technology on cotton output, price, exports and welfare (Experiment E2: Bt cotton adoption by WCA and other regions; factor-neutral technical change)*

Model regions	Share of world exports[a] (%)	Share of world imports[a] (%)	Cotton output		Domestic cotton price		Cotton exports		Welfare (equivalent variation; $US M)[b]	
			Mean (%)	Standard deviation[c] (%)	Mean (%)	Standard deviation[a] (%)	Mean (%)	Standard deviation[c] (%)	Mean (%)	Standard deviation[c] (%)
Bt cotton adopters										
Australia	9.82	0.03	3.84	2.21	−5.17	0.83	7.56	3.31	21.76	9.45
China	0.04	13.34	2.17	0.53	−7.61	1.40	19.90	7.53	562.52	101.82
India	4.02	0.32	3.28	0.84	−11.06	1.97	43.05	12.20	709.63	135.00
USA	28.75	0.35	−1.73	0.46	−2.17	0.35	−4.14	1.15	36.76	21.72
Rest of North America	1.02	5.29	−0.96	0.35	−2.24	0.39	−4.75	1.83	42.71	4.65
Latin America	5.35	11.80	−0.61	0.27	−2.21	0.41	−1.98	1.28	83.20	16.83
South Africa	3.48	0.72	10.98	3.53	−7.40	1.32	18.96	6.10	41.54	9.24
West and Central Africa	12.37	0.15	5.15	1.95	−5.04	0.89	9.61	3.70	81.81	23.86
Nonadopters										
European Union	5.32	17.92	−4.78	0.44	−0.55	0.05	−4.98	0.45	42.24	4.12
Central Asia	20.65	3.99	−6.15	0.50	−0.27	0.02	−7.16	0.58	−23.02	2.25
Middle East/North Africa	5.74	7.63	−2.07	0.19	−0.15	0.01	−9.20	0.79	13.44	2.69
Japan	0.05	5.28	−6.05	0.50	−0.64	0.05	−12.34	1.02	74.60	9.12
Rest of Asia	1.81	26.79	−2.13	0.19	−0.93	0.08	−8.50	0.69	101.33	10.10
Rest of South Asia	1.05	1.27	−0.93	0.08	−0.39	0.03	−10.37	0.87	−9.23	1.25
Rest of World	0.52	5.12	−0.98	0.09	−0.30	0.03	−9.80	0.81	16.17	1.85

Source: Authors' simulation results.
[a] From GTAP database version 5.2.
[b] The welfare analysis does not take into account any monopoly rents by seed supplying firms.
[c] For sensitivity analysis, we employ a Gaussian Quadrature procedure (Arndt and Pearson, 1996) using a triangular-type distribution with the values of the total factor productivity shock ranging from 0.5 to 1.5 times the initial shock level.

land is shifted away from "Other Crops" under E3 (−0.10%) than E2 (−0.01%). Under scenario E4 when transgenic *Bt* productivity is reflected both as labor and chemical input-augmenting technical change, the impact on cotton output and prices is slightly smaller than in either E2 or E3. This result is partly reflected by the underlying production technology and fixed coefficient production technology with CES substitution in value added. As a result, chemical input-augmenting technical change shocks works mostly through reduction of the amount of chemical input, but has smaller cotton output effect given restrictions on substitutions with primary factors.

The comparison across technical change assumptions shows that the main result on cotton output and prices holds with only some variation in magnitude. But the impact on labor demand is qualitatively different depending on the technical change assumptions. Under factor-neutral technical change (E2), both demand for labor and land increase, whereas under the labor-augmenting technical change assumption there is less demand for labor, but demand for land is larger. As transgenic *Bt* technology affects labor use and seasonal distribution (less for pesticide applications but more for harvesting), one potential implication of technology adoption in WCA is a better labor allocation in a multicrop farming as labor released from chemical spraying could be reallocated to better management through weeding and cultivation of food crops and hence improved food crop yields and overall farm productivity. On the other hand, the increased demand for land from the expanding cotton sector implies greater pressure on fallow land and hence lower soil fertility.

The impact of *Bt*-induced technological change on other regions is reported in Table 5. The results are from scenario E2 where all eight regions including WCA adopt *Bt* cotton and where cotton productivity impact is factor-neutral. All adopting regions show cotton price droping due to the *Bt* technology but the size of the drop differs among regions owing to differences in relative size of cotton production, imports and exports and given the intersectoral price linkages. Sectoral impacts show that some regions, such as Australia and South Africa, experience positive changes in producer surplus as cotton output expands more than the price drop. Other regions such as China and Rest of Latin America experience cotton output price drops at a higher rate than output increases. In the United States, cotton output decreases by 1.73% owing to relatively smaller cost reduction from the *Bt*-technology. But all the regions that do not adopt *Bt* cotton technology such as the European Union and Central Asia experience a decrease in cotton output, lower domestic cotton prices and lower exports. At the aggregate, welfare is positive for most regions except for Central Asia and Rest of South Asia, two nonadopting regions who suffer from terms of trade deterioration as net cotton exporters. The welfare gain is relatively larger for China as it benefits from increased cotton technical efficiency without suffering terms of trade losses, as China is a net cotton importer.

Given the uncertainty associated with some of the assumptions behind the estimation of TFP rates for WCA, we have carried out a sensitivity analysis with respect to the level of TFP shocks used in the simulations. We employed a Gaussian Quadrature procedure (Arndt & Pearson, 1996) to obtain estimates of the standard deviations of model results, thereby determining the degree of robustness of results to the productivity shocks. We applied a symmetric, triangular distribution around the calculated cotton TFP rates ranging from 0.5 to 1.5 times the initial shock level used in all scenarios and for all adopting regions. The results of the sensitivity analysis are reported in Table 5 under scenario E2 and show that the results are quite robust to the variation in *Bt*-induced TFP estimate. For example, in the case of WCA, the mean and standard deviation of total welfare gain is $US 81.81 M and $US 23.86 M, respectively.

7. SUMMARY AND CONCLUSIONS

In West and Central Africa (WCA) the cotton sector has performed well in the past and achieved impressive growth by regional standards. Recently, however the sector has been characterized by rising costs, lower yields and declining profitability. The reversal of past performance has brought to the forefront many weaknesses and underscored the sector's vulnerability to international price fluctuations. Moreover, the policy reforms beginning with 1994 CFA Franc devaluation and reduced subsidies from sectoral reforms have raised input costs, leading to cuts in input use by farmers and hence lower yields. If continued, these trends could hamper the future viability of the sector with serious negative consequences for rural welfare, employment and poverty in the region. So the stakes are high, requiring that cost-reducing or yield-improving technologies are critically needed to remedy existing inefficiencies in the cotton production system.

This study sought to evaluate the impact of transgenic insect-resistant technology on WCA cotton. Several reasons have motivated this research. First, there are increasing difficulties with the current patterns of chemical use. Pesticides have become less effective due to rising resistance, compounded by inefficient spraying practices. Second, the cost of insecticides has increased both from the 1994 CFA franc devaluation, the removal of input subsidy in cotton and increased regulatory actions for more strict insecticide use. Also alternative practices for pest control such as threshold-based applications are slow to take hold given their complexity in face of the low literacy rate of farmers and inadequate extension services. Finally, as an alternative technology, *Bt* cotton has been successfully adopted in many other regions that were also faced with pesticide overuse, rising pest resistance, and declining cotton yields. All these considerations, plus the fact that cotton is a nonfood cash crop and therefore raises fewer controversies in international markets, strongly point to a promising positive impact that *Bt* cotton can play in the WCA cotton sector.

Our empirical multiregion general equilibrium analysis shows that under the status quo, where WCA does not adopt transgenic insect-resistant biotechnology while other regions do so, the WCA cotton sector experiences lower earnings for growers, lower exports and a loss of world export share. Social welfare for WCA is reduced by $US 88 million annually. By contrast, the adoption of transgenic *Bt* cotton results in larger producer surplus as cotton output expands at a greater rate than the cotton price decline. Moreover, positive returns to land (which also include agricultural capital) contribute to income gains for farmers. On the trade side, WCA expands exports and slightly increases its global export share. The labor use impact of *Bt* technology may also have positive spillover impact for other farm sectors and hence overall farm income. By reducing in-season labor use from lower pesticide applications, the *Bt* technology helps channel some of this labor to other products such as food crops raising their labor productivity. In addition the positive income effect of the *Bt* cotton technology enables WCA to slightly raise its food imports while maintaining initial production levels. Overall, our general equilibrium analysis shows that with 25% transgenic cotton adoption, welfare for WCA increases from 70 to 100 $US million annually.

These economic gains, however represent only *gross* benefits, and say nothing about the cost or difficulty in achieving the *Bt*-induced productivity gains. For WCA as a whole it may take significant investments to improve access and utilization of promising biotechnologies given the current weak "technology infrastructure" in the region. A recent survey of the region biotechnology showed that apart from tissue culture capacity, the region has limited research capability with substantial infrastructure and training needs to support development of promising new transgenic crops (Alhassan, 2002). Such infrastructure goes beyond just making *Bt* cotton seeds available to farmers, but would enable new research to generate locally-adapted insect-resistant varieties with resistance to broader spectrum bollworm and other pests, and provide technical expertise to implement effective strategies to cope with future developments in insect resistance to *Bt* crops.

In terms of farmers' access to transgenic varieties, the existence of vertically integrated production and marketing structure in WCA could offer advantages. But technology accessibility and affordability will also depend on the type of international partnerships and contractual mechanisms between biotech seed firms and local cotton companies. A prerequisite for such arrangements is the status of biosafety regulations and mechanisms to protect intellectual property rights. Several countries in WCA are reportedly at varying stages of putting biosafety regulations in place, with Cameroon and Côte d'Ivoire ahead of the rest.

Overall, this research shows that estimated gross benefits of the transgenic *Bt* technology to the cotton sector in West and Center Africa would be positive and significant for the cotton sector and the regional economy. Conversely, the cost of not adopting the technology to the WCA economy is also high. While the initial investments in biotechnology in WCA may be significant given the large infrastructure gap, such investments could have positive spillovers beyond the cotton sector.

NOTES

1. West and Central Africa in this paper refer to the following nine cotton growing countries: Benin, Burkina Faso, Chad, Mali, Senegal, Togo, Côte d'Ivoire, Cameroon, and Central African republic.

2. In West Africa, there are four main groups of pests: Bollworms (*Helicoverpa armigera*), leaf-eating caterpillars, mites and sucking pests. In the northern area (from Senegal to Chad) bollworms, bugs, aphids and whiteflies are the key pests. In the coastal countries (from Guinea to Benin) the mite Banks and the Fulso Codling Moth are to be added to the list (Silvie *et al.*, 2001).

3. The model is solved using GEMPACK (Harrison & Pearson, 1996).

4. The ICAC cost of production survey for cotton covers 28 countries and 52 cotton-growing regions, which together combine 85% of world cotton production. Twelve cotton-growing regions from Africa are covered of which six are from West and Central Africa. Cost or production collected include per hectare cost of pre-sowing (land rent, plowing), sowing (seed, irrigation, pre-sowing herbicide) growing (herbicides, fertilizer, insecticides), harvesting (hand/machine picking), ginning, economic costs (management, repairs, overhead) and fixed costs (power, irrigation, tractors, machinery).

5. Declining soil fertility in cotton-based systems result from net outflow of nutrients even when sufficient fertilizer is applied to cotton. This is because, typically farmers in WCA cotton-growing regions do not apply fertilizer to food crops (maize, sorghum, and millet) that are grown in two or three rotations with cotton (Scoones, 2001).

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